The first description of Equidae (Perissodactyla, Mammalia) from Xinyaozi Ravine in Shanxi, North China

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Abstract Abundant mammalian fossils were uncovered during the field exploration for Nihewan beds at the beginning of the 1980s along Xinyaozi Ravine at Nangaoya Township of Tianzhen County, Shanxi Province in North China. But most equid material was not yet described except that of *Equus stenonis*. Six forms of Nihewanian equids were confirmed from the Xinyaozi specimens in the present study, five of which were described for the first time. They include four stenonids such as *Equus sanmeniensis*, *E. teilhardi*, *E. huanghoensis* and *E. stenonis*, and two hipparionines such as *Hipparion* (*Proboscidipparion*) *sinense* and *H.* (*Plesiohiparrion*) *shanxiense*. The diversification of stenonids in the Early Pleistocene was significant in North China with four taxa in Xinyaozi alone. The persistence of Neogene relics such as hipparionines was still present in the Early Pleistocene with two hipparionine taxa in Xinyaozi. *Equus sanmeniensis* and *H.* (*Proboscidipparion*) *sinense* were two representative equids not only coexisted in the Early Pleistocene but also widely distributed in China. The diversity of equids also implies the diversified vegetation on which they depended. The hypsodont dentitions and well developed cement, as well as completely molarized premolars of Xinyaozi equids indicate their abrasive diet mostly on monocotyledonous and grassland habitats with considerable scales enough to nourish six taxa of equids.

Key words Xinyaozi Ravine, Tianzhen, Nihewan Basin; Early Pleistocene, Nihewan beds; Equidae

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1 Introduction

The first material of *Equus* from Nihewan basin was reported by Teilhard de Chardin and Piveteau (1930) as *Equus sanmeniensis* based on the specimens collected from the localities yielding classical Nihewan fauna around Xiashagou (=Hsia-sha-kou) Village. They included

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some equid skull and dentition material into the new equid species established by them, but divided the limb bone material of the species into two forms with larger and smaller sizes respectively. Eisenmann (1975) distinguished the smaller form, including a mandibular fragment with symphysis and lower incisors, a cranial fragment with palate and cheek dentitions and a juvenile left maxillary fragment as a new species *Equus teilhardi* (Eisenmann, 1975) from the specimens of *Equus sanmeniensis* named by Teilhard de Chardin and Piveteau (1930). A third *Equus* from Nihewan Basin, *E. huanghoensis*, was reported from Yangshuizhan (Ao et al., 2013; Li et al., 2016), a fossil locality about 16 km south of Xiashagou Village. *Equus sanmeniensis* was also reported from other Early Pleistocene localities in the Nihewan Basin such as Haojiatai (Huang et al., 1974) about 8 km southwest of Xiashagou, Danangou (Li, 1984) about 20 km south of Xiashagou, Xiaochangliang (Tang et al., 1995) about 7.5 km southwest of Xiashagou, Shanshenmiaozui (Tong et al., 2011a, 2021) about 7.5 km southwest of Xiashagou.

Another equid species, *Hipparion* (*Proboscidiparrion*) *sinense*, was also identified by Teilhard de Chardin and Piveteau (1930) from the material from Xiashagou fossil localities. It was also found from Danangou (Li, 1984) and Xiaochangliang (Tang et al., 1995) coexisted with *E. sanmeniensis*, as well as Daodi (Cai, 1987) 12.5 km south of Xiashagou Village.

The extension of field exploration for Nihewan beds from Yangyuan County to its western adjacent area at the beginning of the 1980s resulted in the discovery of many mammalian fossil localities along Xinyaozi Ravine (Wei, 1997) about 21 km west of Xiashagou Village. The localities are located near Shuichongkou Village and Taijiaping Village along Xinyaozi Ravine and within the Nihewan Rift Valley defined by Niu (2011), and thus the mammalian fossils collected from these localities were regarded as from the same fauna called Xinyaozi fauna (Wei, 1997), which was considered as a part of generalized Nihewan fauna of the Early Pleistocene (Tong et al., 2011b). The uncovered fossils systematically studied include *Postschizotherium intermedium* (Qiu et al., 2002), *Hesperotherium sinense* (Qiu, 2002), *Elasmotherium peii*, *Coelodonta nihowanensis* and *Stephanorhinus* cf. *S. kirchbergensis* (Dong et al., 2021), *Elaphurus bifurcatus*, *E. davidianus predavidianus* (Dong et al., 2019), *Muntiacus bohlini*, *Cervavitus* cf. *C. huadeensis*, *Axis shansius*, *Nipponicervus elegans* (Dong et al., 2020) as well as *Spirocerus wongi* (Bai et al., 2019). The rest of the fossil specimens are still in study. The fossils unearthed from the Shuichongkou deposits indicate an earlier age than that of the classical Nihewan fauna, likely ranging between 1.8 and 2.6 Ma (Qiu et al., 2002). The fossils unearthed from Taijiaping deposits can roughly be considered as contemporary with that of the classical Nihewan fauna (Qiu, 2002), with an estimated age similar to that of Xiashagou dated as ca. 2.2–1.7 Ma (Liu et al., 2012), or equivalent to a range from the upper part of MNQ17 to the lower part of NMQ18 (Woodburne, 2013). An antler of *Cervus* (*Elaphus*) *elaphus* was collected near Dazhuangke Village and its horizon is uncertain if it is the same as those of Taijiaping or Shuichongkou (Dong et al., 2020). Here we systematically describe the equid material from Xinyaozi Ravine at Tianzhen and discuss on their taxonomy from the

Nihewan Beds in addition to a maxillary molar from Shuichongkou area, either M1 or M2, identified by Deng and Xue (1999a, b) as *Equus stenonis*. The localities yielding equid material include Loc. 81017 and Loc. 81018 near Shuichongkou Village, Loc. 81015, probably around Shuichongkou, Loc. 80045 near Taijiaping Village, Loc. 80044 and Loc. 80047 probably around Taijiaping. The dental terminology follows that of Qiu et al. (1987) and Eisenmann (1988). The localities along the Xinyaozi Ravine are briefly called Xinyaozi. The specimens described are housed at the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences (IVPP).

2 Systematic paleontology

Mammalia Linnaeus, 1758
Perissodactyla Owen, 1848
Equidae Gray, 1821
***Equus* Linnaeus, 1758**
***Equus sanmeniensis* Teilhard de Chardin & Piveteau, 1930**

(Fig. 1; Tables 1–2)

Equus sanmeniensis (Larger-sized ones) Teilhard de Chardin and Piveteau, 1930, p. 19–21
Equus cf. *sanmeniensis* (partium) Zdansky, 1935, p. 21–45

Material A right maxillary fragment with P2–M3 (IVPP V31102.1), left P2–P3 (V31102.3), a right mandibular fragment with p2–p4 (V31102.6) and a right mandibular fragment with p3–m1 (V31102.7) from Loc. 81015; a right maxillary fragment with P3–M3 (V31102.2) from Loc. 81018; a right M3 (V31102.4) and a left M3 (V31102.5) from unknown locality along Xinyaozi Ravine.

Diagnosis Large-sized similar to that of *Equus stenonis major*. Skull is long, but its base is narrow and short with elongated snout and narrow frontal. DP1 stably present. Protocone elongated and concave lingually, buccal margins of parastyle and mesostyle of premolars often concave, pli caballine strong, but often diminished with wear, M3 has isolated enamel ring and double-angled occlusal surface. Linguaflexid V-shaped, ectoflexid deep, penetrating into the isthmus, even touching the linguaflexid on lower molars, making lingual margin of linguaflexid and buccal margin of ectoflexid flat. Plications complex, but often diminished with wear (after Eisenmann, 1975 and Deng and Xue, 1999a).

Description Both upper and lower cheek dentitions are hypsodont and covered with a developed cement layer on both lingual and buccal sides adjacent to the grazing area. The measurements of upper and lower cheek teeth are listed in Tables 1–2.

In occlusal view (Fig. 1A, C), the P2 is roughly triangular. The anterostyle is bean-shaped and protrudes forwards from anterior wall of prefossette, its size is slightly smaller than that of the protocone and its neck is quite thick. A lingual fold just behind the neck and on the lingual side of protoloph is moderately developed. The protocone is nearly semicircular with its antero-buccal edge connected with the postero-lingual edge of protoconule. The pli cabalin

is developed; hypoconal groove is developed or closed as islet. The parastyle is moderately developed, the mesostyle is well developed but metastyle is poorly developed. The primary pli protoloph is well developed, the secondary one is absent or moderately developed when present. A single pli protoconule is well developed. While two plis prefossette (*sensu stricto*, similarly hereinafter) are present, the lingual one is more developed than the buccal one. The primary pli postfossette (*sensu stricto*, similarly hereinafter) is well developed, while the secondary one is very weak. A single pli hypostyle is well developed. Both prefossette and postfossette are well closed.

The P3 is roughly trapezoid or quadrate in occlusal view. The protocone is nearly semicircular and elongated; its antero-buccal edge connected with the postero-lingual edge of protoconule; its lingual wall is moderately concave. The pli cabalin is present but not well developed. The hypocone is mostly connected with metaconule or metaloph, and hypoconal groove is widely open. The parastyle is developed, the mesostyle is well developed but metastyle is poorly developed. The primary pli protoloph is well developed, the secondary one

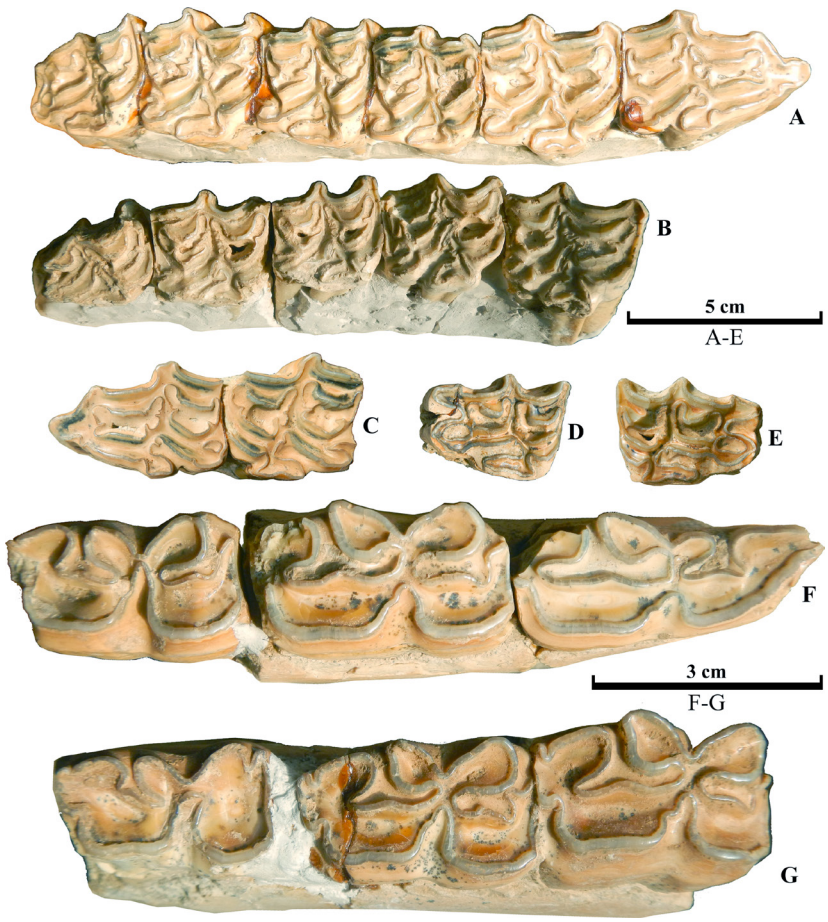

Fig. 1 Occlusal view of maxillary and mandibular fragments of *Equus sanmeniensis* from Xinyaozi
A. right P2–M3 (IVPP V31102.1); B. right P3–M3 (V31102.2); C. left P2–P3 (V31102.3); D. right M3 (V31102.4); E. left M3 (V31102.5); F. right p2–p4 (V31102.6); G. right p3–m1 (V31102.7)

is absent or weak when present. A single pli protoconule is well developed. While two plis prefossette are weak. The primary pli postfossette is well developed, while the secondary one is very weak. A single pli hypostyle is well developed. Both prefossette and postfossette are well closed.

The P4, M1 and M2 are similar to P3, their dimensions tend to reduce irregularly from P3 to M2. The degree of development of pli cabalin is also irregular from P3 to M2. The protocone is generally elongated and concave lingually, its size is close to, but still smaller than, that of the protoconule. Both prefossette and postfossette are well closed.

The M3 is also similar to the central cheek teeth, especially its anterior lobe, but its posterior one is evidently narrower, i.e. its metaconule, postfossette and metacone are all constricted backwards (Fig. 1A–B, D–E). Both prefossette and postfossette are well closed. Hypoconal groove is closed by posterior extensions of hypocone and hypostyle to form hypoconal islet (Fig. 1D–E). The length of the protocone tends to increase irregularly from P2 to M3, while the thickness of the mesostyle tends to decrease gradually from P2 to M3.

Table 1 Measurements of upper cheek teeth of *Equus sanmeniensis* from Xinyaozi and comparison (mm)

	Xinyaozi					XSG[1)]	PL[2)]	ZKD[3)]	XCL[4)]	CTL[5)]
	V31102.1	V31102.2	V31102.3	V31102.4	V31102.5	Spéc. A		V2531	V12033/4	CTL18-1
P2 L	45.46		46.25			45.00			41.00	
P2 W	28.37		28.66						28.50	
P2 Prc L	7.32		6.98							
P2 Prc I	16.10		15.10							
P3 L	34.21	35.86	33.83			34.00		31.6–32.0	31.50	
P3 W	31.72	32.23	32.38					30.5–31.2	31.00	
P3 Prc L	13.07	12.13	12.70					12.00		
P3 Prc I	38.20	33.80	37.50					36.7–37.5		
P4 L	26.97	34.17				33.00		32.1–32	32.00	
P4 W	28.24	31.01						31.1–32	31.00	
P4 Prc L	10.19	11.88						13.20		
P4 Prc I	37.80	34.80						41.12–41.25		
P2–4 L	108.32					113.00				
M1 L	29.85	29.80				32.00	26.50	26–27	29.00	
M1 W	30.16	27.65					32.00	29.60	27.50	
M1 Prc L	13.22	10.73					10.40	12.20		
M1 Prc I	44.30	36.00					35.43	45.1–46.92		
M2 L	31.29	30.62				32.00	29.00	28.5–29		
M2 W	32.63	30.83					31.50	29–29.2		
M2 Prc L	12.38	11.36					11.50	13–13.1		
M2 Prc I	39.60	37.10					39.65	44.83–45.81		
M3 L	32.22	26.74		38.74	37.68	31.00	34.00	27.5–28		34.54
M3 W	27.63	22.64		28.94	28.01		29.00	27–27.5		28.91
M3 Prc L	14.11			15.53	14.20		13.40	13.50		12.14
M3 Prc I	43.80			40.10	37.70		39.41	48.21–49.09		35.15
M1–3 L	94.46	91.88				95.00	86.00			
P2–M3 L	199.72					198.00				

Data source: 1) Teilhard de Chardin and Piveteau, 1930; 2) Chow M C and Liu, 1959; 3) Liu, 1973; 4) Tang et al., 1995; 5) Dong et al., 2017.

Abbreviations: PL. Pinglu; XSG, Xiashagou; ZKD, Zhoukoudian; XCL, Xiaochangliang; CTL, Chutoulang; L, length; W, width; I, index; Prc, protocone.

The p2 is also nearly triangular in occlusal view as its upper counterpart, but longer and narrower. The paraconid is triangular with its postero-vestibular end merged with the anterior part of the protoconid. The paraconid is nearly the same size as that of protoconid. The hypoconid is the largest and longest cusp of the tooth. The oval metaconid is smaller than rounded triangular metastylid, the latter is more lingually placed, and without direct link with the isthmus. All sides of metastylid are convex. The ectoflexid is well developed and widely open, and it is close to isthmus but not yet reaches it. The entoconid is about the same size as that of protoconid. The preflexid is about half size of that of postflexid. The linguaflexid is moderately developed. All flexids are absent of any plication.

The p3, p4 and m1 are generally similar to each other and their crown outline is nearly rectangular. The parastylid is laterally elongated and mesial-distally compressed. The metaconid is slightly larger than metastylid, and they are both more or less angulate. The protoconid is the second largest cusp and the hypoconid is the largest one. The former is slightly wider than the latter, but the latter is much longer than the former. The linguaflexid is V-shaped. The ectoflexid is well developed and reaches the isthmus but still remains on vestibular side as in p3, or penetrates into the isthmus and close to linguaflexid as in p4 and m1. The pli cabalinid is visible only on p3 and absent in the rest. The m2 and m3 are not available.

Comparison and determination The described specimens are evidently of a large-sized *Equus*, e.g. the dental dimensions are significantly large (Tables 1–2), the main cusps are elongated, the protocone of P3–M3 is long and nearly triangular in occlusal view with its lingual side concave and the antero-vestibular side connected to protoconule, the pli cabalin is moderately developed and the enamel plications in both prefossette and postfossette are

Table 2 Measurements of lower cheek teeth of *Equus sanmeniensis* from Xinyaozi and comparison (mm)

	Xinyaozi		XSG[1)]	Gonghe[2)]	Pinglu[3)]	ZKD[4)]	XCL[5)]	Dali[6)]	CTL[7)]
	V31102.6	V31102.7	NIH002	V2423		V2535	V12034	NWUV1325	CTL39/42
p2 L	39.94		36.50	36.00		34.50		32.7–33.9	37.54–39.00
p2 W	16.19			17.50		18.20		15.00	18.75–18.89
p2 p-f	17.83							15.2–15.7	14.54–15.71
p2 pfI	44.60								37.28–41.85
p3 L	33.94	31.84	30.00	31.50		31.50		29.0–29.6	34.98–35.30
p3 W	17.49	18.77		18.00		18.50		17.0–17.9	19.82–21.30
p3 p-f	15.41	14.57						17.5–17.8	11.50–15.25
p3 pfI	45.40	45.80							32.69–43.57
p4 L	30.48	31.79	28.50	29.60	31.00	30.50	29.50	29.4–30.0	32.75–34.10
p4 W	15.51	18.19		18.40	21.50	19.60	19.00	17.0–17.3	20.11–22.84
p4 p-f	8.78	12.78						16.3–17.2	12.09–12.67
p4 pfI	28.80	40.20							36.92–37.16
p2–4 L	106.36			96.80					108.00
m1 L		27.40	28.00	27.30	27.00	27.50	29.50	25.40	29.82–30.33
m1 W		16.59		18.00	20.00	18.00	18.50	16.3–17.0	20.90–21.20
m1 p-f		5.47						13.4–13.5	9.00–10.05
m1 pfI		20.00							30.18–33.14

Data source: 1) Eisenmann, 1975; 2) Chow B X and Liu, 1959; 3) Chow M C and Liu, 1959; 4) Liu, 1973; 5) Tang et al 1995; 6) Deng and Xue, 1999a; 7) Dong et al., 2017. Abbreviations: p-f: postflexid; pfI: postflexid index; for other abbreviations see Table 1.

simple; the double-knot pattern of the lower cheek teeth is stenonid, e.g. the ectoflexid penetrates into the isthmus. Their morphology is mostly in accordance with the diagnosis of *Equus sanmeniensis* defined by Teilhard de Chardin and Piveteau (1930) and redefined by Eisenmann (1975) based on the specimens from Xiashagou, the type locality. The dimension range of upper dentitions of the Xinyaozi covers that of the type locality (Table 1), while the lower one is slightly larger than that of the type locality (Table 2).

Compared with the specimens of *Equus sanmeniensis* from other localities, the dimensions of the Xinyaozi specimens are similar to those from Pinglu (Chow M C and Liu, 1959), Xiaochangliang (Tang et al., 1995) and Chutoulang (Dong et al., 2017), slightly larger than those from Gonghe (Chow B X and Liu, 1959), Zhoukoudian (Liu, 1973) and Dali (Deng and Xue, 1999a). As to the morphology, the shape of the protocone, the thickness of mesostyle, the pattern of double-knots, the enamel plications in Xinyaozi specimens are also very close to those from Pinglu, Gonghe, Zhoukoudian, Xiaochangliang and Chutoulang, but the enamel folds in lower cheek teeth are less numerous in Xinyaozi specimens than those in Gonghe ones (Zheng et al., 1985).

The described specimens are significantly larger than those of *Equus teilhardi* and *Hipparion* (*Plesiohiparrion*) *shanxiense* from the Xinyaozi. Compared with other equids with similar sizes from the Xinyaozi, the protocone is much shorter and rounded in *Equus huanghoensis*; enamel plications in preflexid and postflexid are more evident in *E. huanghoensis* and more complicated in *Hipparion* (*Proboscidipparion*) *sinense*; the preflexid is asymmetric and only the anterior horn is well developed in both *E. sanmeniensis* and *E. huanghoensis* but it bears two symmetrical “horns” pointing in the vestibular direction in *Hipparion* (*Proboscidipparion*) *sinense*; the dental dimensions are slightly larger in *E. huanghoensis*, while slightly smaller in *Hipparion* (*Proboscidipparion*) *sinense*.

***Equus teilhardi* Eisenmann, 1975**

(Fig. 2; Tables 3–4)

Equus sanmeniensis (Smaller-sized ones) Teilhard de Chardin and Piveteau, 1930, p. 19–21

Equus cf. *sanmeniensis* (partium) Zdansky, 1935, p. 21–45

Material A right maxillary fragment with P2–M1 (IVPP V31101.1) from Loc. 80047; a left maxillary fragment with P4–M2 (V31101.2) from unknown locality; a right mandibular fragment with p2–m3 (V31101.3) from Loc. 80045; a right mandibular fragment with m2–m3 (V31101.4) from Loc. 81015.

Diagnosis Species smaller in size than *Equus sanmeniensis* (the lower cheek dentition of a middle-aged individual measures 180 mm), with stenonid lower cheek teeth; the vestibular groove enters the pedicle of the double knot on the lower molars; the lower incisors do not have cups (Eisenmann, 1975).

Description The available specimens are limited and the teeth are hypsodont and covered with a cement layer on both lingual and buccal sides adjacent to the grazing area. The dental measurements are listed in Tables 3–4.

In occlusal view (Fig. 2A), the P2 is roughly triangular. The wearing surface of the anterostyle is nearly oval and its posterior part is connected with the anterior wall of prefossette. The protocone is nearly circular and its antero-buccal edge is connected with the posterior-lingual edge of protoconule. It is slightly wider but shorter than the anterostyle. The pli cabalin is absent. The hypoconal groove is moderately developed and well open. The parastyle is underdeveloped, the mesostyle is well developed but metastyle is either worn or absent. A pli protoloph is present but underdeveloped. A pli protoconule is present and wide. While a pli prefossette is hardly visible. A pli postfossette is present and wide, while other plications are absent in postfossette. Both prefossette and postfossette are self-closed.

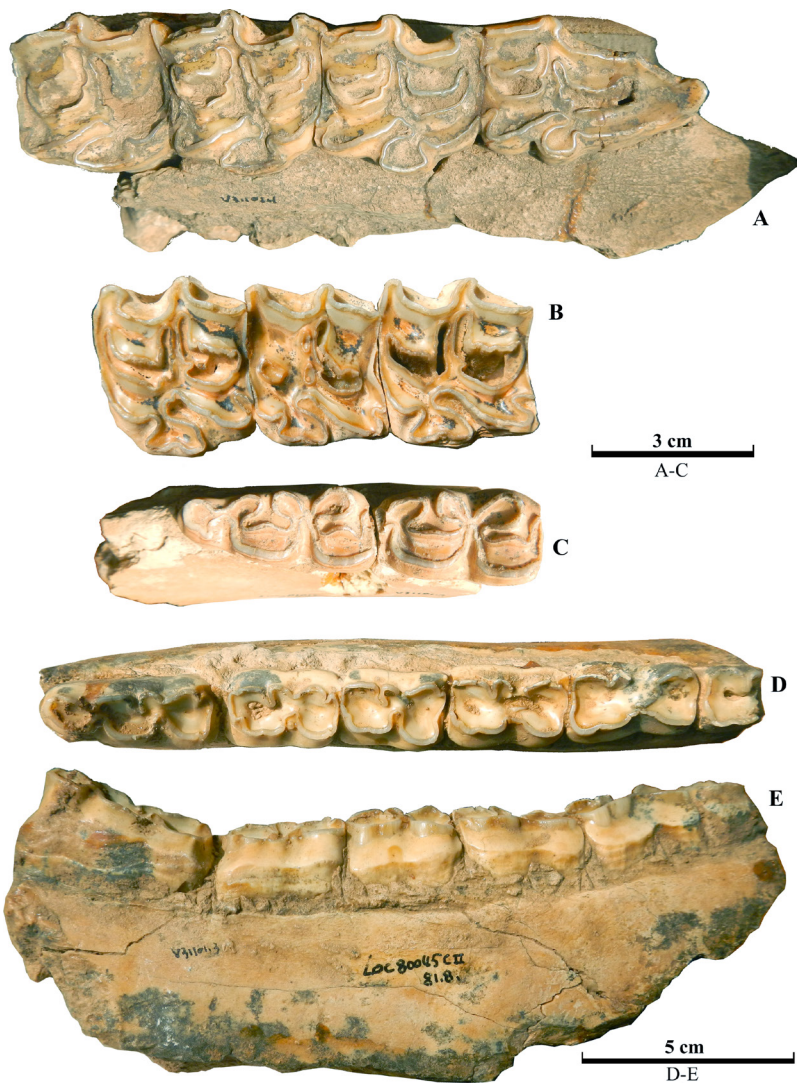

Fig. 2 Maxillary and mandibular fragments of *Equus teilhardi* from Xinyaozi
A. right maxillary fragment with P2–M1 (IVPP V31101.1); B. left P4–M2 (V31101.2);
C. right mandibular fragment with m2–m3 (V31101.4);
D–E. right mandibular fragment with p2–m3 (V31101.3). A–D. occlusal view; E. buccal view

Table 3 Measurements of upper cheek teeth of *Equus teilhardi* and *E. huanghoensis* from Xinyaozi and comparison (mm)

	E. teilhardi				*E. huanghoensis*					
	Xinyaozi V31101.1	Xinyaozi V31101.2	XSG[1)] Spéc. B	Dongtai[2)] M1321	Xinyaozi V31103.1	Pinglu[3)] V2385-9	Xunyi[4)] NWUV1243	Tuozidong[5)] JNTZ6402	YSZ[6)] Male	YSZ[6)] Female
P2 L	41.12		40.00	38.80–39.30	45.78	43.20		46.4–51.64	42	40.3–41.3
P2 W	25.92			27.00–28.00	29.58	31.50		27.4–32.3	27.9–28.9	24.7–25.8
P2 Prc L	6.84			8.20–8.30	6.87	7.50		7.7–8.1	7.3–7.8	7.2
P2 Prc I	16.60			21.10–21.10	15.00	17.36		15.10–17.24	17.4–18.6	17.4–17.9
P3 L	29.58		31.00	29.80–30.60	35.15	35.50		33.7–35.12	34.2–35.0	28.7–29.4
P3 W	29.08			27.90–29.30	34.57	33.50		33.05–34.6	30.1–30.4	27.6–28.1
P3 Prc L	9.12			9.80–10.40	8.21	10.80		8.6–8.9	10.9–11.0	9.8–10.0
P3 Prc I	30.80			32.90–40.00	23.40	30.42		24.71–26.18	31.1–32.2	33.3–34.8
P4 L	28.06	28.64	28.00	27.60–28.20	33.46	35.00–35.5	33.00	31.5–33.4	30.2–30.6	25.5–26.0
P4 W	29.24	23.68		29.40–30.40	34.66	32.20–33.5	31.30	32.5–35.49	30.1–30.4	28.4–28.6
P4 Prc L	11.12	11.92		9.00–10.60	8.74	10.8–10.90	9.20	11.1–11.5	10.8	9.6–9.9
P4 Prc I	39.60	41.60		32.60–37.60	26.10	30.4–31.14	27.88	33.25–36.16	35.3–35.8	37.6–38.1
P2–4 L	101.20		99.00	96.1	117.10				105.5	91.8
M1 L	27.32	24.68	24.00	23.90–24.40	29.87	33.00–31.5	30.90	28.9–29.7	26.0	22.5
M1 W	28.16	30.28		27.10–27.50	30.68	31.5–34.00	31.70	31.3–33.7	27.2–27.4	27.1
M1 Prc L	10.36	9.52		11.20–11.30	8.29	10.9–12.00	11.60	11.5–12	9.0–9.2	9.2
M1 Prc I	37.90	38.60		45.90–47.30	27.80	34.6–36.36	37.54	38.72–41.52	34.2–35.4	40.9
M2 L		27.86	25.00	25.00–25.70	32.18	31.50		29.7–30.4	27.8	25.0–25.8
M2 W		30.15		26.40–27.40	31.25	31.50		30.6–32.4	28.0–28.2	25.8–26.1
M2 Prc L		11.56		10.90–11.30	10.03	10.90		11.8–12.3	11.0	10.3–10.4
M2 Prc I		41.50		43.60–44.00	31.20	34.60		38.82–41.41	39.6	40.3–41.2
M3 L			30.00	26.10–27.40	34.15			31.7–35.6	33.2	27.5–28.1
M3 W				23.60–24.90	29.62			29.1–30.5	26.0–26.8	23.7–24.2
M3 Prc L				10.80–10.90				12.7–13.2	12.6–13.0	11.0–11.1
M3 Prc I				39.40–41.80				35.67–41.64	38.0–39.2	39.5–40.0
M1–3 L			79.00	77.6	97.20				88.9	80.6
P2–M3 L			178.00	176.8	214.70				193	177.7

Data source: 1) Teilhard de Chardin and Piveteau, 1930; 2) Sun et al., 2019; 3) Chow M C and Liu, 1959; 4) Deng and Xue, 1999a; 5) Dong and Fang, 2005; 6) Li et al., 2016. Abbreviation: YSZ, Yangshuizhan; for other abbreviations see Table 1.

The P3, P4, M1 and M2 are similar to each other. Their occlusal view is roughly trapezoid or quadrate, their dimensions tend to reduce irregularly from P3 to M2. The pli cabalin is generally absent and only weakly present on P4. The protocone is between triangular and circular on P3, but nearly triangular from P4 to M2, its size is close to, but still smaller than, that of the protoconule. The enamel plications in prefossette and postfossette are few and weak when present. Both prefossette and postfossette are enclosed. The M3 is not available.

The p2 of V31101.3 is quite worn and broken, and only its posterior third part, e.g. the entoconid, postflexid and most part of hypoconid, is preserved; no plication is present on the preserved part. The rest cheek teeth on V31101.3 are also quite worn and their morphology is not well preserved. The p3, p4, m1 and m2 are generally similar to each other and their crown outline is roughly rectangular. The ectoflexid is shallow and widely open on p3, but gradually becomes deep and narrow from p4 to m2. The specimen V31101.4 with m2–3 is much better preserved. The m2 is nearly rectangular in occlusal view, the parastylid is laterally elongated and mesial-distally compressed. The metaconid is evidently larger than metastylid, and the

former is somewhat round while the latter somewhat angulate. The protoconid is the second largest cusp and the hypoconid is the largest one; the former is slightly wider than the latter, but the latter is much longer than the former. The linguaflexid is V-shaped. The ectoflexid is well developed and penetrates into the isthmus and close to linguaflexid. No enamel plication is present. The m3 is triangular in crown view. Its composition is nearly the same as the m2 except that its hypoconulid is very developed, the latter forms the third lobe of the tooth and with a size similar to that of the entoconid.

Comparison and determination The described specimens are evidently of a relatively small-sized *Equus*, e.g. the dental dimensions are relatively small (Tables 3–4), the main cusps are elongated, the protocone of P3–M2 is long and nearly triangular in occlusal view with its antero-vestibular side connected to the protoconule, the pli cabalin is weakly developed or absent, and the enamel plications in both prefossette and postfossette are nearly absent; the double-knot pattern of the lower cheek teeth is stenonid, e.g. the ectoflexid penetrates into the isthmus. Their morphology is mostly in accordance with the diagnosis of *Equus teilhardi* defined by Eisenmann (1975) based on the specimens from Xiashagou, the type locality. The dimensions of Xinyaozi specimens are very close to those of the type locality (Tables 3–4).

Compared with the specimens of *E. teilhardi* from other localities, the dimensions of Xinyaozi specimens are similar to those from Andersson Loc. 32 at Dongtai (Tung-tai) (Sun et al., 2019), but slightly larger than those of Bajiazui (Deng and Xue, 1999a). As to the morphology, the shape of the protocone, the thickness of parastyle and mesostyle, the development of the pli cabalin, the pattern of double-knots and the enamel plications in Xinyaozi specimens are also very close to those from Dongtai and Bajiazui.

Compared with other equids from the Xinyaozi, the described specimens are the smallest in dimensions, although those of *Hipparion* (*Plesiohiparrion*) *shanxiense* are the closest, but the latter still larger. In addition, the protocone of the latter is fusiform and isolated instead of nearly triangular and linked to the protoconule as in the described specimens, the preflexid of the latter bears two symmetrical “horns” pointing in the vestibular direction instead of being asymmetric and only the anterior horn is well developed as in the described specimens (Fig. 2C).

It is remarkable that the dental dimensions of Xinyaozi specimens are slightly larger than those of the female *E. huanghoensis* from Yangshuizhan (Tables 3–4).

***Equus huanghoensis* Chow B S & Liu, 1959**

(Fig. 3; Tables 3–4)

cf. *Equus huanghoensis* Chow and Chow, 1965, p. 224

Material A left maxillary fragment with P2–M3 (IVPP V31103.1) and a right mandibular fragment with p2–p3 (V31103.3) from Loc. 81015; a right mandibular fragment with p2–m3 (V31103.2) and a left mandibular fragment with p3–p4 (V31103.4) from Loc. 80045.

Diagnosis Large-sized skull with elongated face and snout; outline of parietal part

undulated as seen in lateral view. Nasal-frontal-parietal part has a hollow in middle part and an upturned fore-end, middle groove of nasal bone narrow. Nasal notch deepens to reach level of boundary of P3/P4. Orbit in posterior of cheek teeth row, anterior foramen of palatine canal opens posteriorly; interalveolar margin long. Occipital plane pentagonal; supramagnum protuber strong. Protocone shortened; mesostyle robust, pli caballine very weak, plication simple. Mandible elongated. Condyle of mandible elongated transversely with rounded anterior margin and cupped internally posterior margin. Cups of i3 enclosed, pli caballin weak to absent, enamel plication of postflexid strong, linguaflexid V-shaped (Li et al., 2016).

Description All cheek dentitions are hypsodont and covered with a cement layer on both lingual and buccal sides adjacent to the grazing area. The measurements of upper and lower cheek teeth are listed in Tables 3-4.

In occlusal view (Fig. 3A), the P2 is roughly triangular. The anterostyle is also roughly triangular and connected with parastyle. The protocone is nearly semicircular and its antero-buccal edge connected with the posterior-lingual edge of the protoconule. The pli cabalin is well developed. The hypoconal groove is moderately developed and well open. The parastyle and mesostyle are robust but metastyle is moderately developed. The primary and secondary plis protoloph are well developed. The primary pli protoconule is well developed, some secondary ones are moderately developed. Three plis prefossette are present. The primary pli postfossette is well developed, while two accessary ones are very weak. A single pli hypostyle is well developed. Both prefossette and postfossette are self-closed.

The P3, P4, M1 and M2 are similar to each other. Their occlusal view is roughly trapezoid or quadrate. The protocone is nearly semicircular and antero-posteriorly short; its antero-buccal edge connected with the posterior-lingual edge of protoconule; its lingual wall is generally flat or slightly concave. The pli cabalin is always present but not well developed. The hypocone is fused with metaconule or metaloph, and hypoconal groove is widely open. The parastyle and mesostyle are robust but the metastyle is poorly developed. A single primary pli protoloph is moderately developed. A single pli protoconule is developed. While plis prefossette appear two small ones on P3 and P4, not evident on M1 and M2. The primary pli postfossette is well developed, while the secondary one is very weak. A single pli hypostyle is developed. Both prefossette and postfossette are enclosed.

The M3 is similar to M2, especially its anterior part, but its posterior one, including metaconule, postfossette and metacone are all longer and transversally constricted, and the protocone is triangular and longer than those in the central cheek teeth (Fig. 3A).

The p2 is available in V31103.2 and V31103.3. It is nearly triangular in occlusal view as its upper counterpart, but longer and narrower, while its buccal side is slightly convex and lingual one somewhat concave. The paraconid is roughly equilateral triangular with concave buccal side. The protoconid is fusiform with its anterior end connected with paraconid. The hypoconid is the largest and longest with a developed pli cabalinid at its antero-vestibular side. The metaconid is about the same size as metastylid. The former is somewhat semicircular and

its posterior connected with protoconid by isthmus, while the latter is fusiform, more lingually placed, and without direct link with the isthmus. The ectoflexid is well developed and widely open, and it extends towards isthmus but not yet reaches it. The entoconid is also fusiform and slightly larger than metastylid. It connects hypoconulid by a posterior isthmus. The hypoconulid is lingua-vestibularly compressed. The preflexid is about half length of that of postflexid. The linguaflexid is moderately developed and V-shaped. A developed fold and four minor ones in the postflexid are present in V31103.3, but all absent in V31103.2.

The p3, p4, m1 and m2 are generally similar to each other and their crown outline is between trapezoid and parallelogram. The parastylid is laterally elongated and mesiodistally compressed. The metaconid is slightly larger than or equal to metastylid, and they are somewhat angulate. The protoconid is the second largest cusp and the hypoconid is the largest one. The former is slightly wider than the latter, while the latter is much longer than the former. The linguaflexid is wide and V-shaped. The ectoflexid is well developed and reaches the isthmus but still remains on vestibular side and never penetrates into the isthmus. The pli

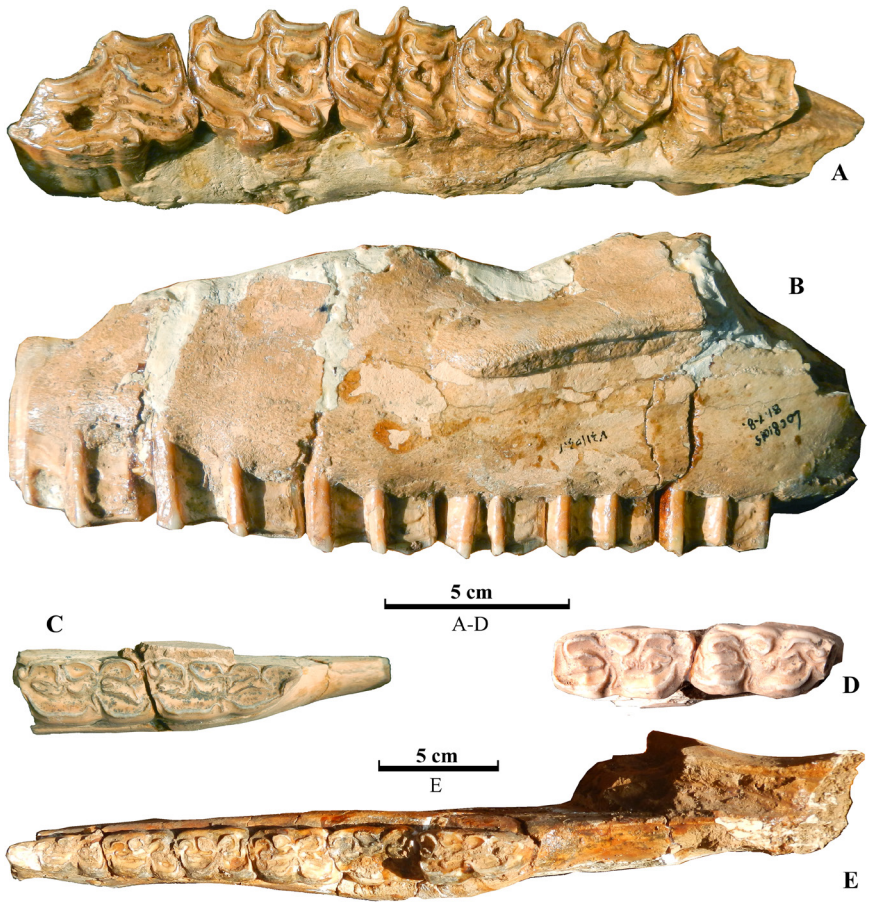

Fig. 3 Maxillary and mandibular fragments of *Equus huanghoensis* from Xinyaozi
A–B. left maxillary fragment with P2–M3 (IVPP V31103.1); C. right p2–p3 (V31103.3); D. left p3–p4 (V31103.4); E. right mandibular fragment with p2–m3 (V31103.2). A, C–E. occlusal view; B. buccal view

cabalinid and plications in postflexid are developed in V31103.3 (p3) and V31103.4 (p3–4), but much less developed in V31103.2 (p3–m2).

The m3 is available in V31103.2 only and its crown is partially broken. The preserved part indicates its occlusal surface is nearly triangular. Its composition is nearly the same as the m2 except that its hypoconulid is very developed and with a size much larger than entoconid.

Table 4 Measurements of lower cheek teeth of *Equus teilhardi* and *E. huanghoensis* from Xinyaozi and comparison (mm)

	E. teilhardi				*E. huanghoensis*				
	Xinyaozi V31101.3	Xinyaozi V31101.4	Xiashagou[1] NIH 001	Bajiazui[2] NWUV1243	Xinyaozi V31103.2	Xinyaozi V31103.3	Xinyaozi V31103.4	YSZ[3] male	YSZ[3] female
p2 L			33	31.8	39.31	41.19		39.6	33.58–34.50
p2 W	17.18			14	17.68	15.02		16	15.20–15.50
p2 p-f				14.4	18.39	18.19		15.6	9.60–12.10
p2 pfl				45.3	46.8	44.2		39.4	27.83–36.03
p3 L	29.16		29	27.4	35.68	33.44	35.81	32.6	27.72–30.72
p3 W	15.63			15.3	21.19	16.29	16.49	17.5–18.9	15.30–15.60
p3 p-f				13	16.56	17.86	17.72	14.8	6.30–9.50
p3 pfl				47.4	46.4	53.4	49.5	45.4	22.73–30.92
p4 L	29.15		29.5	27	32.18		32.03	30.8	27.30–27.90
p4 W	14.61			15.7	18.65		16.68	17.8	15.40–17.30
p4 p-f				12.2	15.23		15.66	13.8	6.50–9.10
p4 pfl				45.2	47.3		48.9	44.8	23.81–32.62
p2–4 L					111.1			99.0	87.70–89.10
m1 L	25.37		25	23.5	30.99			28.1–29.5	25.10–25.88
m1 W	16.41			13.1	17.05			15	14.80–15.60
m1 p-f				7.7	12.11			11	5.60–6.20
m1 pfl				32.8	39.1			37.3–39.2	21.64–24.70
m2 L	27.38	29.73	28	25.5	29.79			28.1	26.02–26.90
m2 W	13.65	14.36		13.5	16.85			15	14.70–15.00
m2 p-f		10.46		8.2	13.58			11.8	6.20–6.70
m2 pfl		35.2		32.2	45.6			42	23.83–24.91
m3 L	38.18	35.15		~30.0	37.74			35.8–36.0	36.10
m3 W	13.52	14.81		11.9	15.42			13.4	13.80
m3 p-f		9.52		8.2	12.5			10	5.10
m3 pfl		27.1		~27.3	33.1			27.8–27.9	
m1–3 L	97.2				101.3			92.0	86.50
p2–m3 L					215.1			190.0	181.00

Data source: 1) Eisenmann, 1975; 2) Deng and Xue, 1999a; 3) Li et al., 2016. For abbreviations see Tables 1–3.

Comparison and determination The significantly large dental dimensions (Tables 3–4), the protocone linked to the protoconule, stenonid pattern of the double-knots etc. indicate the described specimens belong to a large-sized *Equus*. Furthermore, the characters such as shortened protocone with small protocone index, oblique protoloph and metaloph, robust mesostyle, relatively weak pli cabalin, simple enamel plications in upper cheek teeth, developed enamel plications of postflexid and V-shaped linguaflexid in lower cheek teeth, etc. fit well the diagnosis of *Equus huanghoensis* defined by Chow M C and Liu (1959) and supplemented by Li et al. (2016).

Compared with the specimens of *E. huanghoensis* from other localities, the dimensions of the Xinyaozi specimens are very similar to those from Pinglu (Chow M C and Liu, 1959)

and Xunyi (Deng and Xue, 1999a), but slightly smaller than those from Tuozidong (Dong and Fang, 2005) and slightly larger than the male specimens from Yangshuizhan (Li et al., 2016) but much larger than the female specimens from Yangshuizhan (Tables 3–4). As to the morphology, the shape of the protocone, the thickness of mesostyle, the pattern of double-knots, the enamel plications in Xinyaozi specimens are also very close to those from Pinglu, Xunyi, Tuozidong and the male specimen of Yangshuizhan.

The described specimens are dimensionally the largest of all equids from the Xinyaozi. While those of the second largest one, *E. sanmeniensis*, differ from the former by their much longer and angulated protocone and larger protocone index in upper cheek teeth and without developed enamel plications in postflexid in the lower one.

Genus *Hipparion* de Christol, 1832

Subgenus *Proboscidipparion* Sefve, 1927

Hipparion (*Proboscidipparion*) *sinense* (Sefve, 1927)

(Fig. 4; Tables 5–7)

Proboscidipparion sinense n. sp. Sefve, 1927, p. 55–63

Hipparion (*Proboscidipparion*) *sinense* (Larger-sized ones) Teilhard de Chardin and Piveteau, 1930, p. 25–32

Proboscidipparion cf. *sinense* Pei, 1958, p. 361–362

Proboscidipparion sinense Tang et al., 1995, p. 79–80

Material A broken skull with upper dentitions (IVPP V31104.1) and a right maxillary fragment with emerging P2–4 and wearing M1–3 (V31104.2) from Loc. 81018; a broken mandible with incomplete lower dentitions (V31104.3) from Loc. 80044.

Diagnosis Very large hipparion; lacking POF (preorbital fossa); nasals hyper-retracted to posterior half of M1; snout elongate; maxillary and mandibular incisors with longitudinal grooves; maxillary cheek tooth row 165+ mm, with very complex fossette plications; pli caballines bifid to complex, hypoglyphs deeply incised, protocones triangular-shaped being anteroposteriorly long and lingually flattened; mandibular cheek teeth with deeply incised broadly U-shaped linguaflexids, metaconids and metastylids with angular opposing borders, bifid m3 hypoconulids (Sun et al., 2021).

Description The specimen V31104.1 is a broken skull partly restored and without original cranial morphology although all upper dentitions are preserved that the dimensions of all teeth and diastemas can be measured (Tables 5–7). Both upper and lower dentitions are hypsodont and covered with a cement layer on both crown sides adjacent to the grazing area.

The I1 is somewhat triangular and mesiodistally elongated in crown view. The infundibulum is well developed and appears as a long and enclosed fossette in crown view. The entoflexus, a middle enamel groove on the lingual wall of the crown, is well developed. It divides the crown into two lobes, the mesial one is wider than the distal one. The cement layer is thin and covers the basal part of the crown. The I2 is similar to I1, but its mesiodistal dimension is larger and the labial-lingual one is smaller, the wearing surface is oblique to the transection of the tooth. The I3 is more triangular than I1 and I2 in crown view and

dimensionally smaller. The infundibulum is also well developed and nearly fully enclosed, but the entoflexus is quite weak.

The upper canine is smaller than I3, cone-like and mesiodistally flattened. Its mesial and distal edges are sharp.

The P2 is roughly triangular in occlusal view (Fig. 4A, C). The anterostyle is nearly oval and its posterior is fused with protoloph; its size is slightly smaller than that of the protocone. The latter is oval and isolated, without any direct connection with the protoconule. The pli cabalin is developed but without any fusion with the protocone. The hypocone is somewhat triangular and it is connected to metaconule or metaloph by a narrow neck. The hypoconal groove is deep and open. The parastyle and metastyle are developed, but the mesostyle is more developed. Two well developed plis protoloph extend from lingual corner of protoloph towards the paracone. A pli protoconule is well developed. While plis prefossette are not evident due to preservation state. The primary pli postfossette is well developed, while the secondary one is not evident. Two plis hypostyle are well developed. Both prefossette and postfossette are separate from each other.

The P3, P4, M1 and M2 are roughly trapezoid or quadrate in occlusal view. The isolated protocone is between lozenge and oval. The pli cabalin is well developed and tends to fuse with the protocone. The hypocone is between triangular and oval, and connected with metaconule or metaloph by a narrow neck. The hypoconal groove is developed and well open. The parastyle and mesostyle are well developed, the metastyle is developed. The plis protoloph are numerous and well developed. Plis protoconule are well developed. The plis prefossette and postfossette are numerous and developed. Irregular plis hypostyle are developed. Both prefossette and postfossette are filled with complicated enamel plications.

Table 5 Measurements of labial teeth of *Hipparion* from Xinyaozi and comparison (mm)

	H. (*Pr.*) *sinense* V31104.1		*H.* (*Pl.*) *shanxiense* F:AM1118201)		*H.* (*Pr.*) *sinense* V31104.3		*H.* (*Pl.*) *shanxiense* V31105.5		V31105.6	
	left	right			left	right	left	right	left	right
I1 L	18.4	19.25	16.4	i1 L	16.62	16.58	12	13.5	16.16	17.04
I1 W	11.18	11.16	10.9	i1 W	12.6	12.08	12	12.5	11.68	11.42
I1 H	31.6	32.8		i1 H	19.5	19.5			28	33
I2 L	22.92	24.62	17.6	i2 L	17.02	15.1	10	11	17.46	17.76
I2 W	10.32	11.82	10.1	i2 W	11.78	11.82	12.3	12.6	12	12.52
I2 H	30.7	33.6		i2 H	20.5	17	17.1	15.9	23	32
I3 L	18.76	17.62	16.3	i3 L	12.62	15.12	9.7	9.5	16.06	16.02
I3 W	9.08	8.32	7.9	i3 W		10.42	10.3	10.3	9.26	9.28
I3 H	25.05	25.02		i3 H		9	15.1	12.2	16	19
C L	12.78	10.52		c L			9	8.3	8.96	9.02
C W	8.14	6.58		c W			6.2	6.3	7.08	7.1
C H		15.3		c H					18	17
D IC	14.6	15.24		D ic			8.92	9.28	6.5	3.4
D CP	81.6	86.5		D cp			85.26	83.56	72.8	72.5
D IP	107.3	105.6		D ip			103.9	103.2	90.6	89.6

Data source: 1) Bernor et al., 2015; Sun et al., 2021. Abbreviations: D IC, diastema between I3 and C; D CP, diastema between C and P2; D IP, diastema between I3 and P2; for other abbreviations see Tables 1–2.

The M3 is also similar to the central cheek teeth, especially its anterior part, but its posterior one is evidently narrower, e.g. its metaconule, postfossette and metacone are all longer and narrower (Fig. 4A, C). Both prefossette and postfossette are well closed.

The lower incisors are preserved only in V31104.3. The i1 is nearly triangular in occlusal view with both labial and lingual sides longer, convex and mildly undulated with longitudinal grooves. The infundibulum is well developed and appears as an enclosed triangular fossette in crown view. The cement layer is thin and covers the basal part of the crown. The i2 is morphometrically similar to i1, but its wearing surface is more oblique to the transection of the tooth. The i3 is smaller than i1 and i2, and the wearing surface is even oblique. The lower canine is not visible.

The p2 is also nearly triangular in occlusal view as its upper counterpart, but longer and narrower, and its buccal side convex and lingual one slightly concave. The paraconid

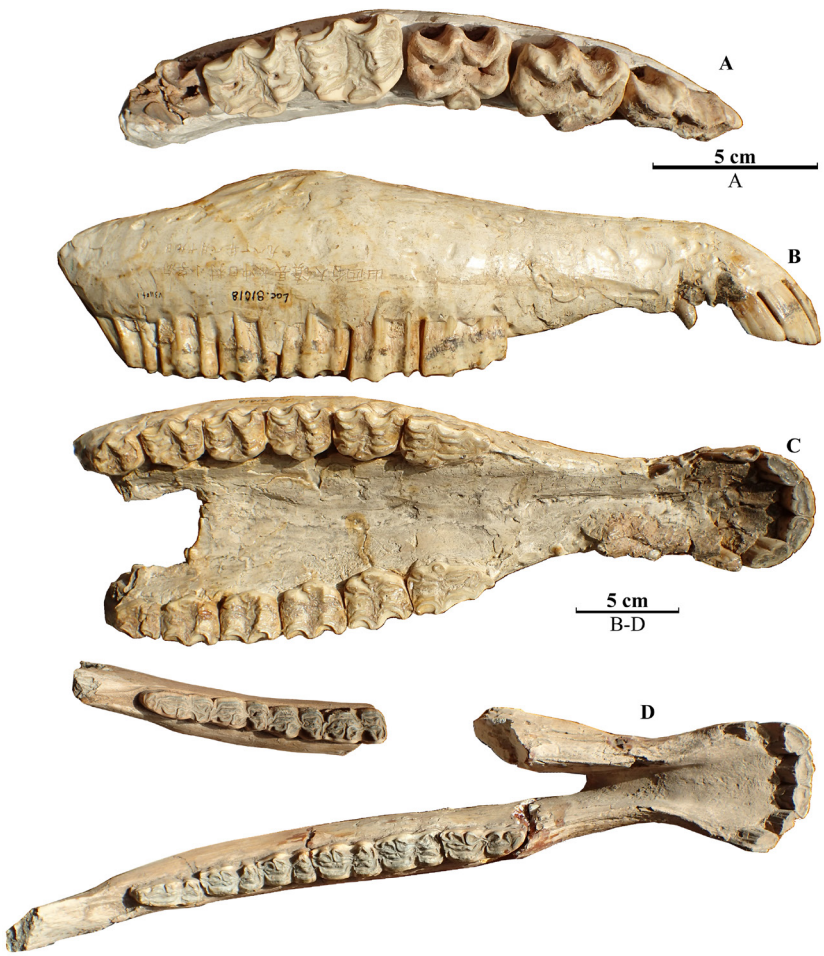

Fig. 4 *Hipparion* (*Proboscidipparion*) *sinense* from Xinyaozi
A. a right maxillary fragment with P2–M3 (IVPP V31104.2); B–C. a broken skull with upper dentitions (V31104.1); D. a pair of broken mandible branches with symphysis and incomplete lower dentitions (V31104.3) A, C, D. occlusal view; B. right buccal view

is isosceles triangular with buccal and lingual sides isometric and concave, and its postero-vestibular end merged with the anterior part of the protoconid. The latter is nearly rectangular. The hypoconid is the largest and longest cusp of the tooth. The metaconid and metastylid are connected with a narrow and long neck. The metaconid is connected with protoconid by the isthmus. The ectoflexid is well developed and widely open, and it is close to isthmus but not yet reaches it. The entoconid is fusiform and about the same size as that of metastylid. It links to hypoconulid with a neck. The preflexid is about half length of that of postflexid. The linguaflexid is moderately developed. Both preflexid and postflexid have numerous but weak enamel wrinkles.

The p3, p4, m1 and m2 are generally similar to each other and their crown outline is nearly trapezoid. The parastylid is laterally elongated and mesial-distally compressed. The metaconid and metastylid are nearly equal sized, more or less triangular. The protoconid is the second largest cusp and the hypoconid is the largest one. The former is slightly wider than the latter, but the latter is much longer than the former. The entoconid is fusiform or semicircular with a size slightly smaller than metastylid and it links to hypoconulid with a moderate neck or pedicle. The hypoconulid is also semicircular and slightly smaller than entoconid. The

Table 6 Measurements of upper cheek teeth of *Hipparion* (*Proboscidipparion*) *sinense* from Xinyaozi and comparison (mm)

	V31104.1 (Left)	V31104.1 (Right)	V31104.2	Xiashagou[1)]	Yushe[1)]	Tuozidong[2)]	Mianchi[3)]	Longdan[1)]	Jinyuan[4)]
P2 L	41.82	41.44	40.86			39.8–46.2		40.50	
P2 W	25.21	23.53	24.83			28.3–29.4		24.60	
P2 Prc L	5.64	5.98						10.80	
P2 Prc I	13.5	14.4						26.67	
P3 L	32.51	32.8	32.88		33	35.6			
P3 W	27.37	27.28	26.99		26.8	28.7			
P3 Prc L	8.26	7.86			7				
P3 Prc I	25.4	24			21.21				
P4 L	30.88	29.67	29.09		28	34.6			28.60
P4 W	25.81	25.84	25.66			32.1			26.00
P4 Prc L	10.38	10.2			8.7				9.50
P4 Prc I	33.6	34.4			31.07				33.22
P2–4 L	107.2	107.1	106.1						
M1 L	28.63	28.16	29.84	29.9	27	29.6–33.2	23.70	29.00	24.80
M1 W	23.67	23.71	23.54	26.8		30.8–31.3	24.20	22.00	24.20
M1 Prc L	7.66	7.39	8.74	8.7			10.20	8.50	8.20
M1 Prc I	26.8	26.2	29.3	29.10			43.04	29.31	33.06
M2 L	29.31	29.17	28.74	29.4		32.3	23.80	26.80	24.50
M2 W	22.46	22.36	23.08	24		27.9	22.50	19.60	22.30
M2 Prc L	7.82	8.38	9.28	10.2			10.00	10.00	9.20
M2 Prc I	26.7	28.7	32.3	34.69			42.02	37.31	37.55
M3 L	24.48	24.77	33.1		31		29.30		27.90
M3 W	18.31	17.84	19.72				20.10		18.70
M3 Prc L							8.85		9.50
M3 Prc I							30.20		34.05
M1–3 L	89.5	88.6	87.5						
P2–M3 L	191.2	194.5	187.3						

Data source: 1) Deng, 2012; 2) Dong and Fang, 2005; 3) Sefve, 1927; 4) Sun et al., 2021. For abbreviations see Table 1.

linguaflexid is developed and widely open, or U-shaped. The ectoflexid is well developed and reaches the isthmus but still remains on vestibular side as in p3 and p4, or penetrates into the isthmus and close to linguaflexid as in m1 and m2. The pli cabalinid is absent. The plications in both preflexid and postflexid are numerous but not intensive.

The m3 is mostly similar to the m2 but narrower and longer. In addition, a reniform talonid with a size similar to that of the hypoconulid is present and links to the hypoconulid on the buccal side.

Comparison and determination The described specimens are evidently of a large-sized *Hipparion*, e.g. significantly large dental dimensions (Tables 5–7), longitudinally grooved enamel on incisors, relatively small, fusiform or oval protocone isolated from protoconule, U-shaped and widely open linguaflexid, numerous small and branching plications in prefossette, postfossette, preflexid and posflexid. Their morphology is mostly in accordance with the description of *H.* (*Proboscidipparion*) *sinense* established by Sefve (1927) and redefined by Sun et al., (2019), but their dimensions are slightly larger than those of the type locality (Tables 6–7).

Table 7 Measurements of lower cheek teeth of *Hipparion* (*Proboscidipparion*) *sinense* from Xinyaozi and comparison (mm)

	V31104.3 (Left)	V31104.3 (Right)	Mianchi[1)]	Yushe[2)]	Hongya, Heshui, Qiahe[2)]	Tuozidong[3)]	Jinyuan[4)]
p2 L		39.69	32	33		37.5–42.4	33.2–33.5
p2 W		14.59	14	13.1		14.2–15.2	13.8
p2 p-f		18.68					
p2 pfl		47.1					
p3 L		32.06	26	26.4–27.0		32.4	28.1–28.6
p3 W		15.77	15	15.0–15.8		14.8	15–15.2
p3 p-f		18.05					
p3 pfl		56.3					
p4 L	30.99	31.36	26	25.1–26.6	30.5	32.3	27.7–28.9
p4 W	15.94	15.91	15	14.5–15.0	15.5	13.7	15.1–15.3
p4 p-f	17.56	17.09					
p4 pfl	56.7	54.5					
p2–4 L		102.3	87				
m1 L	26.89	27.14	26	23.5	24.8		25.2–25.9
m1 W	13.02	13.61	16	13.5–14.0	12.6		12.8–13
m1 p-f	12.3	12.19					
m1 pfl	45.7	44.9					
m2 L	28.75	28.75	23	23.9–25.2	27.9		28.9
m2 W	12.38	12.56	14.5	13.5–14.3	14.7		12
m2 p-f	14.11	13.88					
m2 pfl	49.1	48.3					
m3 L	30.7	31.46	33	34.6	28		
m3 W	12.62	12.74	12	11.1	10.9		
m3 p-f	15.55	16.21					
m3 pfl	50.7	51.5					
m1–3 L	88.8	89.5	82				
p2–m3 L		193	168				

Data source: 1) Sefve, 1927; 2) Qiu et al., 1987; 3) Dong and Fang, 2005; 4) Sun et al., 2021. For abbreviations see Tables 1–2.

Compared with the specimens of *H.* (*Proboscidipparion*) *sinense* from other localities, the dimensions of the Xinyaozi specimens are similar to those from Xiashagou and Hongya in the Nihewan Basin (Qiu et al., 1987) and from Longdan (Deng, 2012), slightly larger than those from Yushe Basin (Qiu et al., 1987) and Jinyuan (Sun et al., 2021), slightly smaller than those from Tuozidong (Dong and Fang, 2005). As to the morphology, the shape of the protocone, the thickness of mesostyle, the pattern of double-knots, the enamel plications in Xinyaozi specimens are also very close to those from Xiashagou, Hongya, Longdan, Yushe, Jinyuan and Tuozidong, with only some minor differences as the detailed shape of the protocone, the exact number of enamel plications within the intraspecific variations.

The described specimens are significantly larger than those of *Equus teilhardi* and *Hipparion* (*Plesiohiparrion*) *shanxiense* from the Xinyaozi. They differ from other equids with similar sizes from the Xinyaozi such as *E. sanmeniensis* and *E. huanghoensis* by isolated protocone, complicated plications in prefossette, postfossette, preflexid and posflexid.

Subgenus *Plesiohipparion* Qiu et al., 1987

***Hipparion* (*Plesiohiparrion*) *shanxiense* (Bernor et al., 2015)**

(Figs. 5–6; Tables 5, 8–9)

Plesiohiparrion shanxiense n. sp. Bernor et al., 2015, p. 199–208

Material A broken palate with right P2–4 and left P2–3 (IVPP V31105.1), a left maxillary fragment with P4–M3 (V31105.2), a right maxillary fragment with P4–M3 (V31105.3), two pairs of incomplete mandibles with lower dentitions (V31105.5, V31105.6) from Loc. 81018; a right maxillary fragment with P2–M1 (V31105.4) from Loc. 80045; a left mandibular fragment with p2–m3 (V31105.7) from Loc. 81017.

Diagnosis Advanced hipparionines of large size, without POF. Basilar length about 500 mm. Nasal notch shallow, its posterior border anterior to P2, IOF (infraorbital foreman) above P3; labial surface of incisor provided with grooves, infolding band crenulated; cheek teeth high-crowned, protocone elongated and pointed at ends; double-knot houfenoid in pattern (metaconid and metastylid symmetrically triangular in form), ectoflexid shallow, constricted at its outlet by well-developed pli antecaballinid and/or pli caballinid, sometimes with pli hypostylid (Sun et al., 2021).

Description Both upper and lower dentitions are hypsodont. The cheek teeth are covered with a developed cement layer on both lingual and buccal sides adjacent to the grazing area, while labial teeth are covered with a thin layer of cement on crown base. The measurements of upper and lower cheek teeth are listed in Tables 8–9.

In occlusal view, the P2 is approximately triangular. The anterostyle is semicircular and completely fused with protoloph; its size is slightly larger than that of the protocone. The protocone is bean-like and isolated. Pli cabalin is moderately developed. The hypoconal groove is present and widely open. The parastyle and metastyle are moderately developed, while the mesostyle is well developed. The pli protoloph is absent or moderately developed when present. A single pli protoconule is weak. The plis prefossette and postfossette are numerous

but not well developed. The prefossette is much larger than postfossette.

The P3, P4, M1 and M2 are similar to each other. The occlusal surface is roughly trapezoid or quadrate. The protocone is fusiform and isolated. The pli cabalin is well developed and about to fuse with the protocone. The hypocone is mostly fused with metaconule or metaloph, and hypoconal groove is short and widely open. The parastyle and mesostyle are well developed but metastyle is moderately developed. A vertical groove is present on buccal wall of the parastyle. The primary pli protoloph is well developed, the accessary ones are irregular and weak. Two developed plis protoconule are present with one or more smaller ones around. While plis prefossette are numerous and weak. A primary pli postfossette is well developed, while the secondary one is weak and a third one is even weaker. A single pli hypostyle is well developed. Both prefossette and postfossette are enclosed.

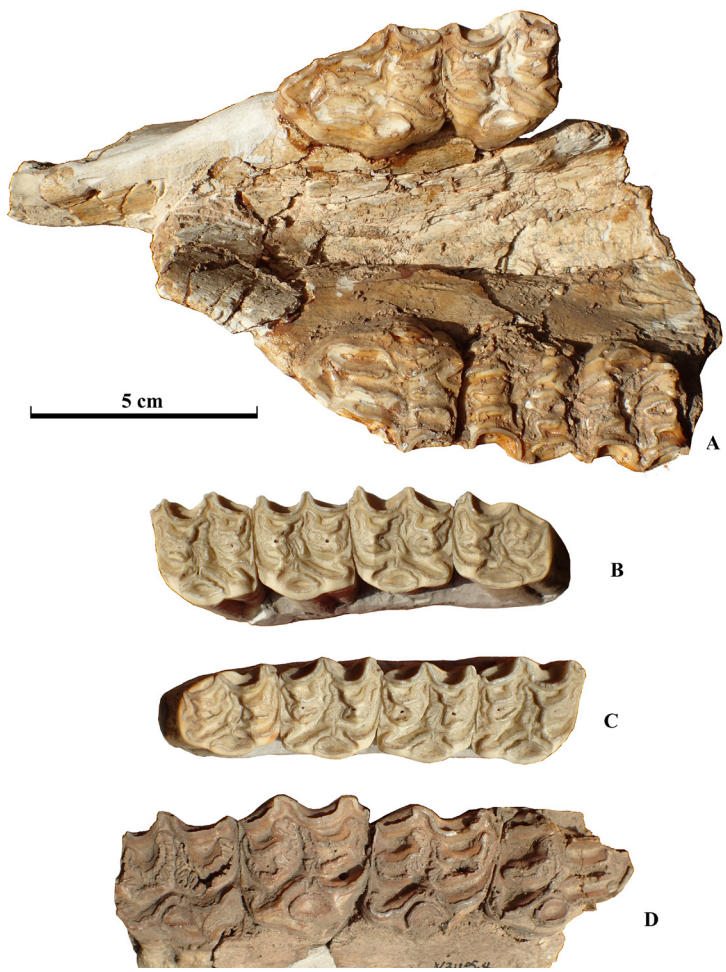

Fig. 5 Occlusal view of maxillary fragments of *Hipparion* (*Plesiohiparrion*) *shanxiense* from Xinyaozi
A. broken palate with right P2–4 and left P2–3 (IVPP V31105.1);
B. left maxillary fragment with P4–M3 (V31105.2); C. right maxillary fragment with P4–M3 (V31105.3);
D. right maxillary fragment with P2–M1 (V31105.4)

The M3 is also similar to the central cheek teeth, especially its anterior lobe, while its posterior one is evidently narrower, i.e. its metaconule, postfossette and metacone are all constricted backwards. In addition, the protocone is longer but narrower, the metastyle is more developed, hypoconal groove is larger, while hypocone is smaller. Both prefossette and postfossette are well closed.

The lower labial teeth are preserved in V31105.5 and V31105.6, but those in V31105.5 are mostly broken, and those in V31105.6 are relatively better preserved. The i1 is nearly triangular in occlusal view with both labial and lingual sides longer, convex and mildly undulated. The well-developed infundibulum appears as an enclosed triangular fossette in crown view and more lingually located, with its inner walls wrinkled. The cement layer is thin and covers the basal part of the crown. The i2 is morphometrically similar to i1, but its wearing surface is more oblique to the transection of the tooth. The i3 is smaller than i1 and i2, and the infundibulum opens a small lingual gap on the tip of the crown. The lower canine is spear-shaped, located close to i3 and smaller than i3.

The p2 is also nearly triangular in occlusal view as its upper counterpart, but longer and narrower, with its buccal side convex. The paraconid is triangular and its vestibular angle merged with the anterior tip of the fusiform protoconid, whose posterior end merged

Table 8 Measurements of upper cheek teeth of *Hipparion* (*Plesiohiparrion*) *shanxiense* from Xinyaozi and comparison (mm)

	V31105.1		V31105.2	V31105.3	V31105.4	DLJ 190624-580	F:AM111820
	left	right				Jinyuan[1)]	Shouyang[2)]
P2 L	36.52	36.19			35.38		36.9
P2 W	23.86	24.59			23.11		29
P2 Prc L	8.37				7.76		11.4
P2 Prc I	22.9				21.93		30.89
P3 L	25.42	25.87			26.62	30.9	28.2
P3 W	25.34	25.7			25.16	24.7	26.7
P3 Prc L	10.17				8.09	11.5	11.4
P3 Prc I	40				30.39	37.22	40.43
P4 L		25.31	24.82	23.72	25.76	28.4	25.5
P4 W		24.85	24.81	24.39	24.62	24	26.7
P4 Prc L		9.98	9.56	9.45	8.65	11.2	10.7
P4 Prc I		39.4	38.5	39.8	33.6	39.44	41.96
P2–4 L		87.54			87.28		90.7
M1 L			22.58	22.24	22.67	25.3	24.2
M1 W			22.64	22.34	23.57	23.2	25
M1 Prc L			8.28	8.33	7.68	9.1	10.2
M1 Prc I			36.7	37.5	33.9	35.97	42.15
M2 L			22.61	22.4		26.8	25.2
M2 W			21.97	22.31		21.4	25.5
M2 Prc L			8.8	8.9		9.7	11
M2 Prc I			38.9	39.7		36.19	43.65
M3 L			20.99	21.67		25.4	24
M3 W			18.27	19.43		17	21
M3 Prc L			10.1	9.38		9.1	11.3
M3 Prc I			48.1	43.3		35.83	47.08
M1–3 L			66.32	67.26			73.7

Data source: 1) Sun et al., 2021; 2) Bernor et al., 2015; Sun et al., 2021. For abbreviations see Table 1.

with the anterior end of hypoconid. The latter is longer than protoconid. The oval metaconid and triangular metastylid are nearly equal-sized. A relatively long isthmus links between the posterior tip of metaconid and that of protoconid. The triangular entoconid with a size similar to that of metastylid merges its buccal angle with laterally compressed hypoconulid. The preflexid is shorter than postflexid, and both of them are relatively wide. The pli cabalinid and a pli postflexid are present in V31105.6 but absent in V31105.5 and V31105.7. The ectoflexid is underdeveloped in V31105.6, but moderately developed and near the isthmus in V31105.5 and V31105.7. The linguaflexid is moderately developed and widely open.

The p3, p4, m1 and m2 are generally similar to each other and their crown outline is quadrilateral or nearly rectangular, their length is much larger than their width and their anterior width is slightly larger than the posterior one. The parastylid is laterally elongated and mesial-distally compressed. The metaconid and metastylid are somewhat triangular and with similar sizes. The protoconid is the second largest cusp and the hypoconid is the largest one. The former is slightly wider than the latter, but the latter is evidently longer than the former. The entoconid is also triangular or fusiform with its posterior end fused with laterally elongated hypoconulid. The preflexid is shorter than postflexid, and their width becomes narrower from p3 to m2. The linguaflexid is widely open. In V31105.5 and V31105.7, the ectoflexid is well developed and reaches the isthmus but still remains on vestibular side as in p3 and p4, or penetrates into the isthmus and close to linguaflexid as in m1 and m2. But in V31105.6, the ectoflexid is weak in the p3 and moderate in the p4, well developed and reaches the isthmus but still remains on vestibular side in m1 and m2. The pli cabalinid is well developed in p3 and p4 of V31105.6, moderately developed in m1 and m2 of V31105.6, as well as in p3 and p4 of V31105.5, very weak or absent in m1 and m2 of V31105.5, as well as in p3 to m2 of V31105.7.

The m3 is mostly similar to the m2 but narrower and much longer, somewhat triangular in crown view. Furthermore, a reniform talonid with a size laterally wider than that of the hypoconulid is present and links to the hypoconulid near the buccal side.

Comparison and determination The described specimens are evidently of a relatively large-sized *Hipparion*, e.g. large dimensions of cheek teeth, protocone isolated from protoconule, numerous plis prefossette and postfossette, houfenoid double-knots. Moreover, longitudinally grooved enamel on incisors, relatively long and fusiform protocone, strongly concave buccal walls of paracone and metacone, metaconid and metastylid symmetrically triangular in form, ectoflexid shallow in premolars and deep in molars, constricted at its outlet by developed pli antecaballinid and/or pli caballinid. It is remarkable that among three mandibular specimens described above, the cheek teeth of V31105.5 and V31105.7 as well as the molars of V31105.6 are nearly the same among each other and in accordance with the diagnosis of *Hipparion* (*Plesiohiparrion*) *shanxiense* established by Bernor et al. (2015) and redefined by Sun et al. (2021), although the dimensions of described specimens are slightly smaller than those of the type (Tables 8–9). While the premolars of V31105.6 are somewhat

different from those of V31105.5 and V31105.7, as well as the type. The ectoflexid of V31105.6 is nearly absent in the p2, weak in the p3 and moderate in the p4; the pli caballinid of V31105.6 is very developed in the p2, well developed in the p3 and developed in the p4. The differences might be a result of different stages of wearing or sexual dimorphism, but also might indicate an unknown species of hipparion.

Compared with the specimens of *H.* (*Plesiohiparrion*) *shanxiense* from other localities, the dimensions of the Xinyaozi specimens are similar to those from Yushe (Qiu et al., 1987) and slightly smaller than those from the Jinyuan Cave (Sun et al., 2021); the protocone is more elongated and the buccal walls of paracone and metacone are less concave in Jinyuan specimens.

The described specimens are apparently smaller than those of *H.* (*Proboscidipparion*) *sinense* from the Xinyaozi (Tables 6–7) although they belong to a relatively large-sized hipparion compared with the earlier relatives. They differ from other equids with similar sizes from the Xinyaozi such as *Equus teilhardi* by isolated protocone, complicated plications in prefossette and postfossette, as well as houfenoid double-knots.

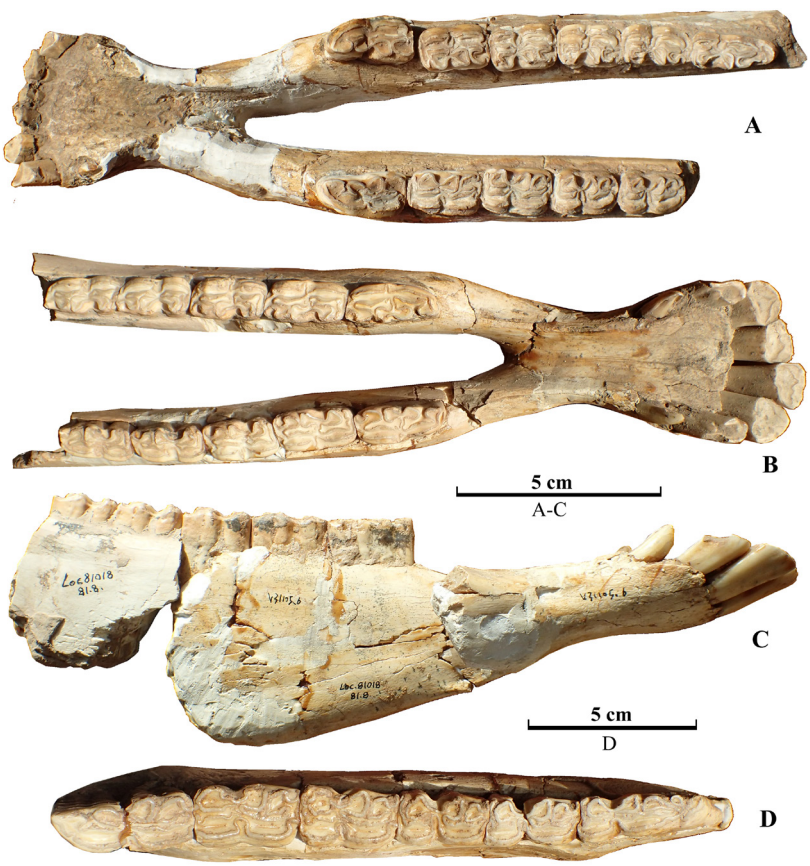

Fig. 6 Mandibular fragments of *Hipparion* (*Plesiohiparrion*) *shanxiense* from Xinyaozi
A–C. incomplete mandibles with lower dentitions: A. IVPP V31105.5, B–C. V31105.6;
D. left mandibular fragment with p2–m3 (V31105.7). A, B, D. occlusal view; C. right buccal view

Table 9 Measurements of lower cheek teeth of *Hipparion* (*Plesiohiparrion*) *shanxiense* from Xinyaozi and comparison (mm)

	V31105.5		V31105.6		V31105.7	THP20619	F:AM111820
	left	right	left	right		Yushe[1)]	Shouyang[2)]
p2 L	29.78	30.06	31.86	31.93	33.61	32.9	32.7
p2 W	12.89	13.27	14.36	14.15	14.49	14.3	15.6
p2 p-f	12.93	13.58	13.93	14.15	15.6		14.8
p2 pfl	43.4	45.2	43.7	44.3	46.4		45.26
p3 L	25.6	24.79	28.11	29.13	26.78	26.3	26.9
p3 W	13.44	13.51	14.59	14.75	15.19	14	17.4
p3 p-f	12.77	11.94	12.44	12.71	13.47		16
p3 pfl	49.9	48.2	44.2	43.6	50.3		59.48
p4 L	24.96	24.61	26.34	26.1	26.44	25.4	25
p4 W	14.64	13.61	13.98	14.01	15.97	14.2	17
p4 p-f	12.76	11.96	11.24	11.19	14.33		14.8
p4 pfl	51.1	48.6	42.7	42.9	54.2		59.20
p2–4 L	81.28	84.26	87.68	87.62	87.66		85.3
m1 L	22.74	22.09	24.67	25.75	24.24	24	24.1
m1 W	12.99	13	13.08	12.62	14.57	13.2	16.4
m1 p-f	7.89	7.91	10.33	10.34	11.43		15.8
m1 pfl	34.7	35.8	41.9	40.2	47.1		65.56
m2 L	23.47	22.96	24.28	25.37	25.96		28.4
m2 W	13.22	12.36	12.94	11.6	12.88		15.4
m2 p-f	9.16	9.15	11.29	11.55	12.24		13.9
m2 pfl	39	39.9	46.5	45.5	47.1		48.94
m3 L		28.01			33.75		27
m3 W		10.96			12.51		12.1
m3 p-f		11.74			16.77		12
m3 pfl		41.9			49.7		44.44
m1–3 L		75.02			82.62		79.6
p2–m3 L		158.2			189.3		165

Data source: 1) Qiu et al., 1987; 2) Bernor et al., 2015. For abbreviations see Tables 1–2.

3 Discussion

3.1 Nihewanian stenonid horses from Xinyaozi

Four stenonid taxa were confirmed from the Xinyaozi material in the present study, including *Equus sanmeniensis* firstly identified by Wei (1997) and described in the present paper, *Equus stenonis* firstly identified and described by Deng and Xue (1999a) and accepted by the present authors, as well as *E. teilhardi* and *E. huanghoensis* newly identified from Xinyaozi specimens and described in the present paper. *E. sanmeniensis* specimens were unearthed from Locs. 81015 and 81018, i.e. around Shuichongkou Village, from the lower horizon; *E. teilhardi* and *E. huanghoensis* specimens were collected together from Locs. 81015 and 80045, i.e. around Shuichongkou and Taijiaping villages, from both upper and lower horizons. While *E. stenonis* specimen was from an unknown locality along Xinyaozi Ravine, either upper or lower horizon.

E. sanmeniensis is the first identified stenonid from Xinyaozi specimens. It is a common equid taxon in the Early Pleistocene faunas in northern China. It was firstly discovered from

Xiashagou in the Nihewan Basin in Hebei Province (Teilhard de Chardin and Piveteau, 1930) and rediscovered from other localities in the Basin (Huang et al., 1974; Li, 1984; Tang et al., 1995; Tong et al., 2011a). The localities yielded the taxon distribute in Henan (Zdansky, 1935), Shanxi (Zdansky, 1935; Pei, 1958; Chow M C and Liu, 1959; Chia and Wang, 1978), Shandong (Zdansky, 1935; Lü et al., 1989), Qinghai (Chow B S and Liu, 1959); Gansu (Xie, 1983) and Shaanxi (Hu and Qi, 1978; Deng and Xue, 1999a; Xue et al., 1999) provinces, as well as in Nei Mongol Autonomous Region (Zdansky, 1935; Dong et al., 2017) and Beijing Municipality (Teilhard de Chardin, 1936; Liu, 1973). *E. sanmeniensis* was also reported from Transbaikalia and northern Mongolia (Erbajeva and Alexeeva, 2000; 2013). But the *E. sanmeniensis* described by some authors (e.g. Zdansky, 1935; Hu and Qi, 1978; etc.) from northern China was considered as a complex of *E. sanmeniensis*, *E. teilhardi* and probably *E. qingyangensis*, *E. huanghoensis* (Forsten, 1986; Deng and Xue, 1999a). And that from the Late Pleistocene of Yushu in Jilin described by Hu and Liu (1959) was regarded as *E. dalianensis* (Zhou et al., 1985; Deng and Xue, 1999a), that from the Middle Pleistocene of Jinniushan and Miaohoushan in Liaoning described by Jinniushan Joint Excavation Team[1)] (1976) and Zhang et al. (1986) respectively were also regarded as *E. dalianensis* (Deng and Xue, 1999a). The Middle Pleistocene *Equus* cf. *E. sanmeniensis* from Maoershan in western Liaoning is metrically similar to *E. sanmeniensis* and morphologically between *E. sanmeniensis* and *E. dalianensis* (Fu et al., 2012). Its long protocone with concave lingual side in P4–M3, the presence of groove on buccal side of mesostyle in P2–4, ectoflexid penetrates into isthmus in lower molars, etc. are similar to *E. sanmeniensis*. But its protocone of P2 and P3 is not very long, pli cabalin in upper cheek teeth is not well developed, linguaflexid is U-shaped etc. are similar to *E. dalianensis*. Its taxonomic status is therefore not certain, and more likely a transitional form from *E. sanmeniensis* to *E. dalianensis*. Xinyaozi specimens are the earliest record of *E. sanmeniensis*, which was widely distributed and its geographic distribution is within the range of the Palearctic realm in East Asia (Fig. 7).

E. stenonis from Xinyaozi was firstly identified by Deng and Xue (1999a, b). The skull from Taigu is also included into this species (Sun and Deng, 2019). *E. stenonis* was widespread in Eurasia in the Early Pleistocene (Prat, 1980; Sotnikova et al., 1997; Forsten, 1999; Eisenmann and Kuznetsova, 2004; Palombo and Alberdi, 2017; Cirilli et al., 2021). Although its fossil records in China are limited only in Shanxi Province, the specimen from Xinyaozi was considered the earliest record of *E. stenonis* and the species might therefore originate from Shanxi Province (Deng and Xue, 1999a; Sun and Deng, 2019). While Eisenmann (2004) described some specimens of *E. stenonis* from Saint Vallier, ca. 2.2 Ma which was regarded as its oldest occurrence in Europe (Bernor et al., 2019) and it is probably contemporary to Xinyaozi specimen.

E. teilhardi was identified and established by Eisenmann (1975) from the specimens

1) The joint excavation team composed of researchers from IVPP, Liaoning Provincial Museum, Liaoning Provincial Bureau for Geological Survey, Yingkou Municipal Bureau for Culture and Yingkou County Office for Culture.

previously named by Teilhard de Chardin and Piveteau (1930) as *E. sanmeniensis*. The former is smaller than the latter, and differs from the latter additionally by the absence of infundibulum in lower incisors (Eisenmann, 1975). The taxon was later found from Bajiazui in Gansu Province (Deng and Xue, 1999a) and Dongtai in Shanxi Province (Sun et al., 2019). Xinyaozi is the fourth site yielding *E. teilhardi*. By the way, some specimens from Mianchi and Lantian identified as *E. sanmeniensis* by Zdansky (1935) and Hu and Qi (1978) were also regarded as *E. teilhardi* (Deng and Xue, 1999a). The appearance of the taxon in the Nihewanian deposits is more frequent than *E. stenonis*, but much less frequent than *E. sanmeniensis*.

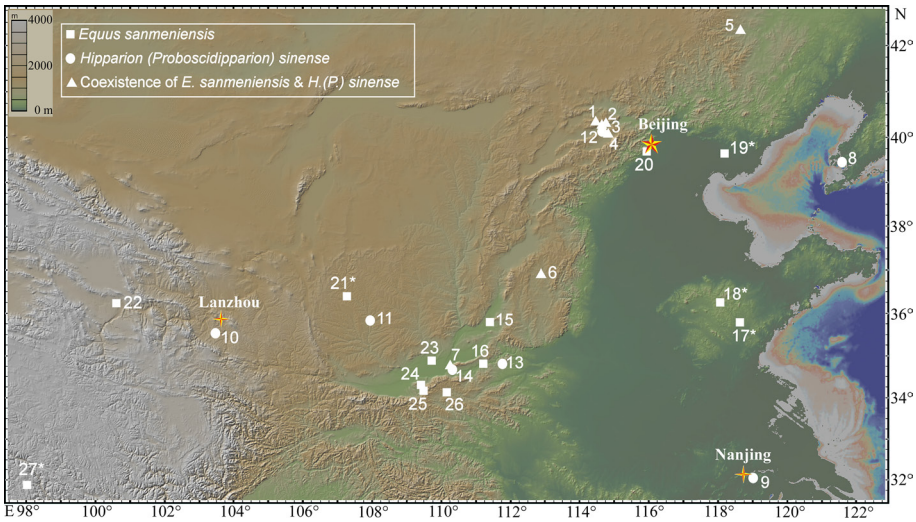

Fig. 7 Geographic distribution of *Equus sanmeniensis* and *Hipparion* (*Proboscidipparion*) *sinense* in China
Fossil localities: 1. Xinyaozi; 2. Xiashagou (=Hsia-sha-kou); 3. Xiaochangliang and Haojiatai; 4. Danangou; 5. Chutoulang; 6. Yushe; 7. Xihoudu; 8. Jinyuandong Cave; 9. Tuozidong cave; 10. Longdan; 11. Muqi; 12. Hongya; 13. Langou (=Lan-kou); 14. Kehe; 15. Xiangfen; 16. Pinglu; 17. Xiaozhangshan; 18. Qizianshan; 19. Jiajiashan (=Chiachiashan); 20. Zhoukoudian (=Chouk'outien); 21. Gengjiagou; 22. Gonghe; 23. Dali; 24. Laochihe; 25. Gongwangling; 26. Longyadong cave; 27. Dedeng

E. huanghoensis was firstly named based on some upper cheek teeth from Pinglu (Type locality) and Yushe in Shanxi Province (Chow M C and Liu, 1959). It is a large-sized horse, even larger than *E. sanmeniensis*. It was uncovered later from Linyi, northwest of Pinglu, in Shanxi Province with some isolated teeth (Chow and Chow, 1965), from Xunyi in Shaanxi Province with upper dentitions (Deng and Xue, 1999a), from Tuozidong in Nanjing of Jiangsu Province with broken skulls (Dong and Fang, 2005), from Yangshuizhan in the Nihewan Basin in Hebei Province with nearly complete skulls associated with mandibles (Li et al., 2016). The specimens from Pinglu to Yangshuizhan increased from just some isolated teeth to nearly complete skulls and that enriched a lot the morphological information about the taxon. Xinyaozi is the seventh site yielding the taxon. The specimens from Yangshuizhan include a nearly complete skull with mandibles from a same male individual, and a broken skull and mandibles with nearly complete dentitions from a same female (Li et al., 2016).

Xinyaozi specimens are morphometrically similar to the male specimens from Yangshuizhan but evidently larger than the female specimens (Tables 3–4). The latter is also dimensionally similar to the specimens of *E. teilhardi* from Xinyaozi and elsewhere. The lower incisors of the female *E. huanghoensis* from Yangshuizhan are aged and worn and it is impossible to judge if the infundibula existed to exclude them from *E. teilhardi*. Their stenonid lower cheek teeth have characters of both *E. teilhardi* and *E. huanghoensis*. It is possible that the female specimens from Yangshuizhan actually belong to *E. teilhardi*. It is also possible that the specimens of *E. teilhardi* from Xinyaozi belong to the female of *E. huanghoensis* because no lower incisors without infundibulum were found from the Xinyaozi.

3.2 Phylogenetic considerations of stenonid horses from Xinyaozi

Eisenmann and Kuznetsova (2004) interpreted the history of monodactyl equids as an evolution of (at least some) extant *Equus* species from primitive Pliocene or Early Pleistocene *Plesippus* (mostly of North America) and/or *Allohippus* (mostly of the Old World). They included the Old World stenonid or stenonoid horses into *Allohippus* with subgenus or even genus rank. The stenonids from the Xinyaozi might be named as *Allohippus sanmeniensis*, *A. teilhardi*, *A. stenonis* and *A. huanghoensis* based on their interpretation. However, Cirilli et al. (2021) supported *Equus* as being a single clade and denied *Plesippus* and/or *Allohippus* at either the generic or subgeneric rank. Since it is impossible to check the validity of fossil taxonomy with reproductive isolation as for extant species, morphologic taxonomy is a very practical way for fossil classification and that leaves consequently many controversies in paleontological taxonomy. Also as a practical way, we support to maintain the traditional classifications as much as possible to minimize the burden for the colleagues of other disciplines or of future generations to learn the complicated evolution of taxonomy of the groups.

Sun and Deng (2019) retained Chinese stenonid horses within *Equus*, and they conducted a cladistic analysis on the phylogeny of Chinese stenonids. They found that *E. huanghoensis* and *E. stenonis* form a sister group, while *E. sanmeniensis* forms a sister group with *E. wangi*, *E. teilhardi* forms a sister group with *E. yunnanensis*. *E. sanmeniensis* is closer to *E. huanghoensis* and *E. stenonis* than to *E. teilhardi*; *E. huanghoensis*, *E. stenonis* and *E. teilhardi* have the parallel deriving sequence but *E. sanmeniensis* derived in a later sequence. We agree that *E. sanmeniensis* and *E. huanghoensis* are closer to each other than to *E. teilhardi* based on our studied specimens from the Xinyaozi.

3.3 Nihewanian hipparionine horses from Xinyaozi

Hipparion (*Proboscidipparion*) *sinense* is the first identified hipparionine taxon from Xinyaozi specimens (Wei, 1997) and the specimens were unearthed from Loc. 81018 and Loc. 80044, i.e. from both upper and lower horizons along Xinyaozi Ravine. Its records in the Nihewan Basin were firstly noted by Teilhard de Chardin and Piveteau (1930) for the specimens from Xiashagou localities and then from surrounding Nihewanian localities

(Huang et al., 1974; Li, 1984; Cai, 1987; Tang et al., 1995). But the specimens from Xiashagou described by Teilhard de Chardin and Piveteau (1930) were excluded from *H.* (*Proboscidipparion*) *sinense* and only a mandibular fragment collected from Xiashagou by Licent in the 1920s and housed in Tianjin Natural History Museum was regarded as true *H.* (*Proboscidipparion*) *sinense* (Qiu et al., 1987). Although the first occurrence of *Hipparion* in the Old World, well known as *Hipparion* Datum, has been regarded as a geochronologic mark for early Late Miocene (Bernor et al., 2017; Sun et al., 2021), *Hipparion* experienced a massive recession in the Early Pleistocene after a successful diversification through the Neogene (Qiu et al., 1987; Sun et al., 2021). *H.* (*Proboscidipparion*) *sinense* is a remarkable survivor of hipparionine horses and frequently co-exited with *Equus* in the Early Pleistocene mammalian faunas in northern China (Tang et al., 1983; Qiu et al., 1987). Its presence in Xinyaozi fauna is a further example (Fig. 7).

Hipparion (*Plesiohiparrion*) *shanxiense* from Xinyaozi is the second identified hipparionine taxon and its first record from the Nihewanian localities around the Nihewan Basin (*sensu stricto*). The specimens were collected from Locs. 81017, 81018 and Loc. 80045, i.e. from both upper and lower horizons along Xinyaozi Ravine. The taxon was firstly recognized by Bernor et al. (2015) from the specimens collected from Xiazhuang (=Hsi Chwang) at Shouyang County of Shanxi Province and housed in the American Museum of Natural History, and later reported by Sun et al. (2021) from Luotuoshan in Dalian, Liaoning Province. Xinyaozi specimens are the third records of the taxon. It is the third taxon of the Early Pleistocene hipparionine horses reported in China besides *H.* (*Proboscidipparion*) *sinense* and *H.* (*Plesiohipparion*) *houfenense*.

3.4 Paleoecologic consideration of equids from Xinyaozi

The cheek dentitions of both stenonids and hipparionines from Xinyaozi are hypsodont and covered with cement layer of considerable thickness, and their premolars are completely molarized. The hypsodont dentitions are evidently built to compensate the abrasion by tough vegetation such as monocotyledonous herbs, while cement was considered as the reinforcement to hold enamel plates together in adaptation of the abrasive diet (Niven and Wojtal, 2002). As mentioned above, six equid taxa were identified from Xinyaozi deposits with at least five and probably all six taxa in the same horizon. How did such numerous equids share the same grassland along Xinyaozi Ravine is an interesting question. Our interpretation is that the equids were migrating grazers and they roved around from one grassland to another from time to time in search of fresh grass as modern equids in wide condition (Nowak and Paradiso, 1983). And all identified equid taxa did not gather together at one time, but alternately present at a locality along the ravine that they could avoid direct competition for food resources. On the other hand, dental morphology of six fossil equids from Xinyaozi is different from each other and that implies their food resources were presumably different, e.g. the preference for tips or stems of certain grass besides the preference for different forage, etc. The completely molarized premolars double dental abrasion surface in contrast to unmolarized premolars in

ruminants with smaller abrasive surface. It is a significant difference between ruminants and hindgut caecum equids.

Both hindgut caecum fermentation hipparionines and rumen fermentation ruminants have suspending lateral toes and suitable for slope grazing. The recession and extinction of hipparionines and the rise of ruminants in the Early Pleistocene indicate that digestive strategy of hindgut caecum fermentation is less competitive than that of ruminants' rumen fermentation.

4 Conclusion

Six forms of Nihewanian equids were identified from the Xinyaozi specimens, five of which were described for the first time in the present work. They include four stenonids such as *Equus sanmeniensis*, *E. teilhardi*, *E. huanghoensis* and *E. stenonis*, and two hipparionines such as *Hipparion* (*Proboscidipparion*) *sinense* and *H.* (*Plesiohiparrion*) *shanxiense*.

Diversification of stenonids in the Early Pleistocene is significant in North China with four taxa in Xinyaozi alone. The persistence of Neogene relics such as hipparionines is still present in the Early Pleistocene with two hipparionine taxa in Xinyaozi. The diversity of equids also implies the diversified vegetation on which they depended.

The hypsodont dentitions and well developed cement, as well as completely molarized premolars of Xinyaozi equids indicate their abrasive diet mostly on monocotyledonous and grassland habitat with considerable scale enough to nourish six taxa of equids.

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山西天镇辛窑子早更新世马科化石新材料

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摘要：20世纪80年代在桑干河盆地一带考察泥河湾层时，在山西省天镇县南高崖乡的辛窑子沟一带发现了很多哺乳动物化石地点并出土了大量哺乳动物化石。最近的研究系统记述了马科化石的5个种，加上此前曾记述过的1个种，在辛窑子沟一带的早更新世地层中

产出的马科化石至少有6个种。其中古马型马有4种：三门马(*Equus sanmeniensis*)、德氏马(*E. teilhardi*)、黄河马(*E. huanghoensis*)和古马(*E. stenonis*); 两种三趾马：中国长鼻三趾马(*Hipparion* (*Proboscidipparion*) *sinense*)和山西近三趾马(*H.* (*Plesiohiparrion*) *shanxiense*)。研究表明在早更新世期间新出现的古马型马的多样性是显著的，仅在辛窑子动物群中就有4种。而延续到早更新世的三趾马这些新近纪残留类群在辛窑子动物群中仍然有两个种。三门马和中国长鼻三趾马是早更新世期间真马与三趾马共存的最典型代表。它们在中国的产出地点很多，分布也较广，并有较大幅度的重叠。辛窑子动物群中马科化石种类的多样性表明它们所依赖摄食的植被也应存在较大的多样性。高冠的颊齿和发育的白垩质及完全臼齿化的前臼齿指示这些马科种类食物粗糙，很可能是单子叶草类。它们的栖息地应为草原草甸环境，且其范围较大，以便满足6个马科种类在那里摄食与活动。

关键词：山西天镇辛窑子沟，泥河湾盆地；早更新世，泥河湾层；马科

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